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POWER SPECTRA AND NOISE-REDUCING QUALITIES OF LASA BEAMS

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By

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TELEDYNE, INC.

Under

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POWER SPECTRA AND NOISE -REDUCING QUALITITES
OF LASA BEAMS

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TABLE OF CONTENTS

	Page No.
ABSTRACT	
INTRODUCTION	1
PROCEDURE	1
RESULTS	2
Short-period Noise	2
Long-period Noise	3
CONCLUSIONS	4
REFERENCE	4

TABLES

LPZ Sensor Groups For N=5 and N=9	Table 1

ILLUSTRATIONS

LASA LPZ Response "A" - E4 Subarray	Figure 1
Recursive Bandpass Filter Used in LPZ Data Preparation	Figure 2
Noise Power Spectra for E3 Beams 08 March 1967	Figure 3
Noise Power Spectra for E3 Beams 10 March 1967	Figure 4
Noise Power Spectra for E3 Beams 11 March 1967	Figure 5
Noise Power Spectra for E3 Beams 17 March 1967	Figure 6
Noise Power Spectra for 7-Element E3 Beams 08 March 1967	Figure 7
Noise Power Spectra for 7-Element E3 Beams 10 March 1967	Figure 8
Noise Power Spectra for 7-Element E3 Beams 11 March 1967	Figure 9
Noise Power Spectra for 7-Element E3 Beams 17 March 1967	Figure 10
Noise Power Reduction for 7-Element E3 Beams	Figure 11
Average Long Period Noise Reduction at the Montana LASA Using Two Experimental Methods	Figure 12

ABSTRACT

Noise power levels at 1 cps were found to be about the same on outputs of E3 subarray beams composed of 18, 19, and 25 elements. This is attributed either to a higher average input noise level for the 25-element beam, or to the possibility that noise is more highly correlated between the additional channels of the larger beam.

In those cases where the number of short-period beam inputs is held constant at 7 and spacing between adjacent sensors is changed progressively from 3 to 9.5 kilometers, noise power at 1 cps is reduced approximately by a factor of N for spacings equal to or greater than 6 kilometers.

If the number of long-period inputs to a beam is held constant at either 5 or 9 and spacing between adjacent sensors is changed progressively from 10 to 60 kilometers, the average rms level at the input and the noise based on zero-lag correlations are reduced approximately by a factor of $N^{\frac{1}{2}}$ for spacings greater than 20-30 kilometers.

INTRODUCTION

Short-period (SPZ) and long-period (LPZ) LASA data are discussed concurrently in this report. The results for SPZ data supplement SDL Report No. 198,"A Beamforming Study Using Outputs from the Extended E3 Subarray at the Montana LASA". The objective here is to present plots of noise power spectral estimates of outputs from E3 beams. We are interested first in the general similarities of the spectra, and second in the effect of inter-sensor spacing on noise power reduction at the output of 7-element beams.

The LPZ data relate long-period noise reduction to inter-sensor spacing at the Montana LASA. Our basic procedure was to prefilter and beamsteer a fixed number of traces while varying the spatial separation of elements contributing to the beams. We are interested specifically in the average rms noise reduction as well as the decrease in the level of noise which is computed from the zero-lag correlations.

PROCEDURE

Our short-period data are noise seismograms recorded by vertical-component sensors in the extended E3 subarray at the Montana LASA during the period 8-17 March 1967. The data, which were recorded between the hours 7:00 PM and 4:30 AM (Montana local time), were detrended and demagnified before infinite-velocity beams were formed. Magnification levels for 11 January 1967 were used to convert trace displacement, in counts, to equivalent earth motion, in mμ, at 1 cps. Power spectra are based on prefiltered (0.4-3.0 cps) outputs from the beams and individual sensors using 60 seconds of data (1200 digital points) and 120 lags.

In the case of 7-element beams, short-period noise power reduction at each frequency was computed in the following manner:

$$db = 10 \log \left[\frac{\text{power on beam output}}{\text{average power input}}\right]$$

The long-period noise seismograms used in this study were recorded by vertical-component sensors in the interval 18 November 1966-20 January 1967. During the period LPZ seismometers at the Montana LASA were operating on response "A", which peaks at a period of 25 seconds in a manner similar to that shown in Figure 1. Prior to forming infinite-velocity beams, we detrended, demagnified, and prefiltered the time series. Magnification levels for 6 March 1967 were used to correct the traces to equivalent earth motion at the peak response. A 4-pole Butterworth filter was used to limit the traces to the band 15-50 seconds; the filter response is shown in Figure 2.

Two experimental methods were used to compute long-period noise reduction as follows:

$$db = 20 \log \left[\frac{\text{rms on beam output}}{\text{average rms input}}\right]$$

and

$$db = -10 \left[\log N - \log \{1 + (N-1)\tilde{\rho}\}\right]$$

where $\tilde{\rho} = \bar{M}/\bar{N}^2$ is the ratio of the average zero-lag cross-correlation to the average zero-lag autocorrelation, as described by Hartenberger and Shumway (1967). Each long-period beam was formed several times, using a different noise sample each time to obtain the average noise reduction values plotted on Figure 12.

RESULTS

Short-period Noise

Figures 3 through 6 are plots of noise power as a function of frequency for data recorded on March 8, 10, 11, and 17 respectively. Decibel scales and arrows marking the 1 cps power points have been added to facilitate interpretation. The average of the 25 individual spectra is also shown on each

figure. Noise power peaks at 0.5 and 2 cps predominate on most of the spectra; an exceptionally high value at 2.3 cps is shown in Figure 3.

Referring to Figure 3, it is interesting to note that noise power at 1 cps at the output of the 19-element beam is about the same as that on the 25-element beam output. A similar relationship is observed between the 25-element and 18-element beams shown in Figures 4 and 5. Equivalent noise power levels at 1 cps on outputs of 18, 19, and 25-element beams are attributed either to a higher average input to the 25-element beam or to the possibility that the noise is more correlated between the additional channels of the larger beam.

Figures 7 through 10 are plots of noise power versus frequency for outputs from 7-element E3 beams; recording dates and time intervals correspond to those in Figures 3 through 6, respectively. We have included these data to illustrate the effects of inter-sensor spacing, Δ, which changes from 3 kilometers on the left side of the figures to 6, 8, and finally 9.5 kilometers on the right. This effect is further illustrated in the following discussion.

Noise power reduction (in db) at the output of 7-element E3 beams is shown as a function of inter-sensor spacing in Figure 11. For the frequencies shown, these data correspond to those shown in Figures 7-10, but are more meaningful in the sense that the noise reduction is relative to the average power input to the beams at each frequency. As shown in Figure 11, noise power at 1 cps is reduced approximately by a factor of N at $\Delta \geq 6$ km.

Long-period Noise

We said above that our basic procedure was to beemsteer a fixed number of traces, N, while varying inter-sensor spacing, Δ. Table 1 shows that long-period sensor groups used

here and corresponding approximate spacing intervals and beam apertures.

Our results are summarized in Figure 12 which shows average noise reduction, in db, as a function of sensor spacing, in kilometers, for two experimental methods. In the case of N=5 in Figure 12, both methods have reduced the noise nearly by a factor of $N^{\frac{1}{2}}$ at Δ = 20 km. On the other hand, for Δ = 30 km noise has been reduced by more than a factor of $N^{\frac{1}{2}}$. A similar result is observed for N=9, although in this case we were unable to form a beam for Δ = 20 km.

CONCLUSIONS

The following conclusions are based on beamforming studies which used short-period vertical-component seismograms recorded in the extended E3 subarray at the Montana LASA, as well as long-period vertical-component LASA data.

1. Short-period beams consisting of 18, 19, and 25 inputs from the E3 subarray have approximately the same noise level at 1 cps. This is due either to a higher average input noise level for the 25-element beam, or to the possibility of more highly correlated noise between the additional channels of the larger beam.

2. Seven-element E3 beams reduce noise power at 1 cps nearly by a factor of N for average adjacent-sensor spacings equal to or greater than 6 kilometers.

3. Long-period beams composed of either 5 or 9 vertical-component LASA seismograms reduce average input rms noise levels and average mean square noise by a factor of $N^{\frac{1}{2}}$ at sensor spacings greater than approximately 20-30 kilometers.

REFERENCE

Hartenberger, R.A., and Shumway, R.H., 1967 "A Beamforming Study Using Outputs From the Extended E3 Subarray at the Montana LASA," Report No.198, Seismic Data Laboratory, Teledyne, Inc.,Alexandria, Virginia.

TABLE I

LPZ SENSOR GROUPS FOR N=5 AND N=9

N	SENSORS	≈ SPACING (KM)	≈ APERTURE (KM)
5	AO. B1-4	10	18
5	AO, C1-4	15	30
5	C2-4, D2-3	20	38
5	AO, D1-4	30	56
5	AO, E1-4	60	116
5	AO, F1-4	100	200
9	AO, B1-4, C1-4	10	30
9	AO, C1-4, D1-4	15	56
9	AO, D1-4, E1-4	30	116
9	AO, E1-4, F1-4	60	200

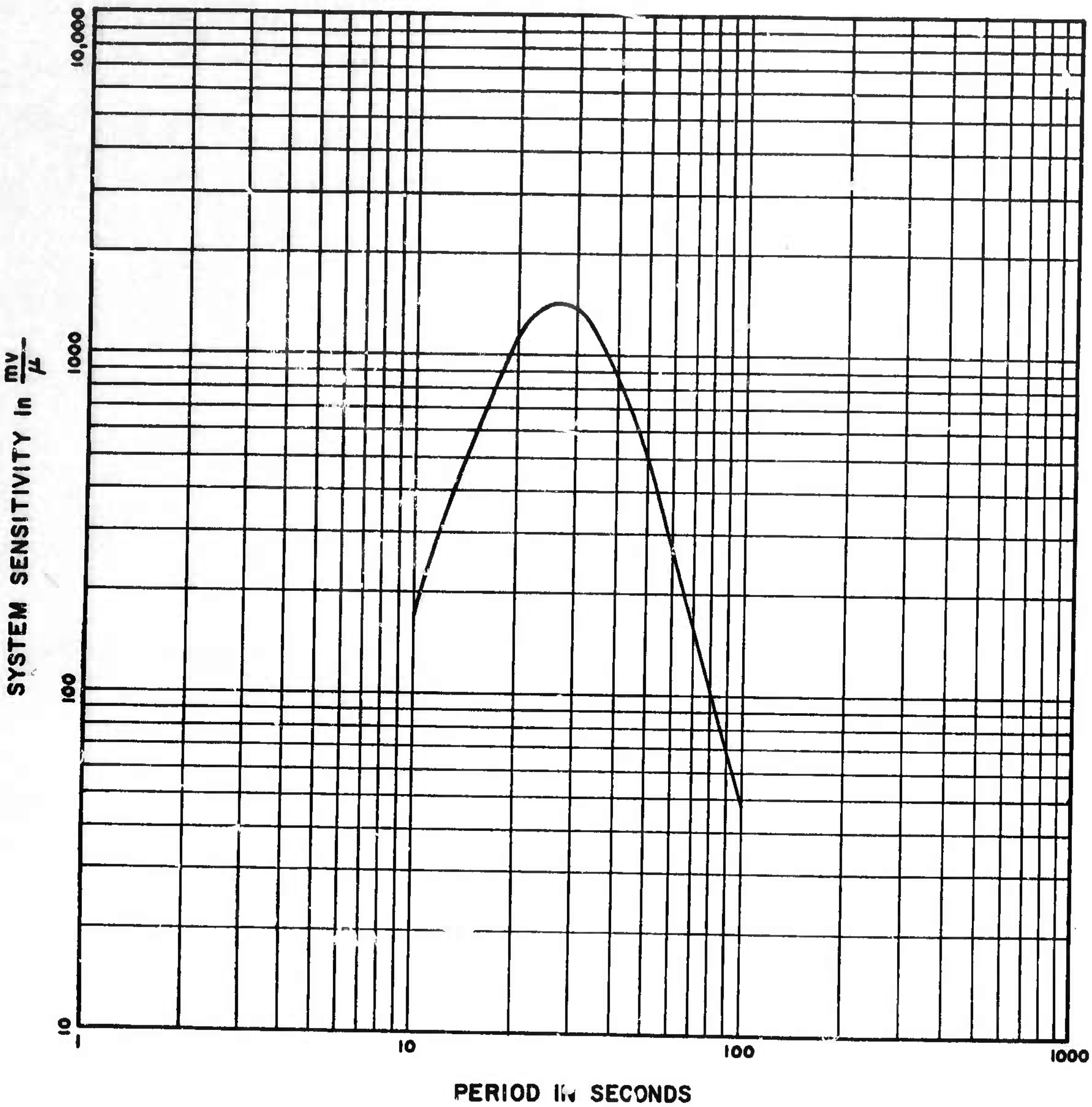

Figure 1 - LASA LPZ Response "A" - E4 Subarray

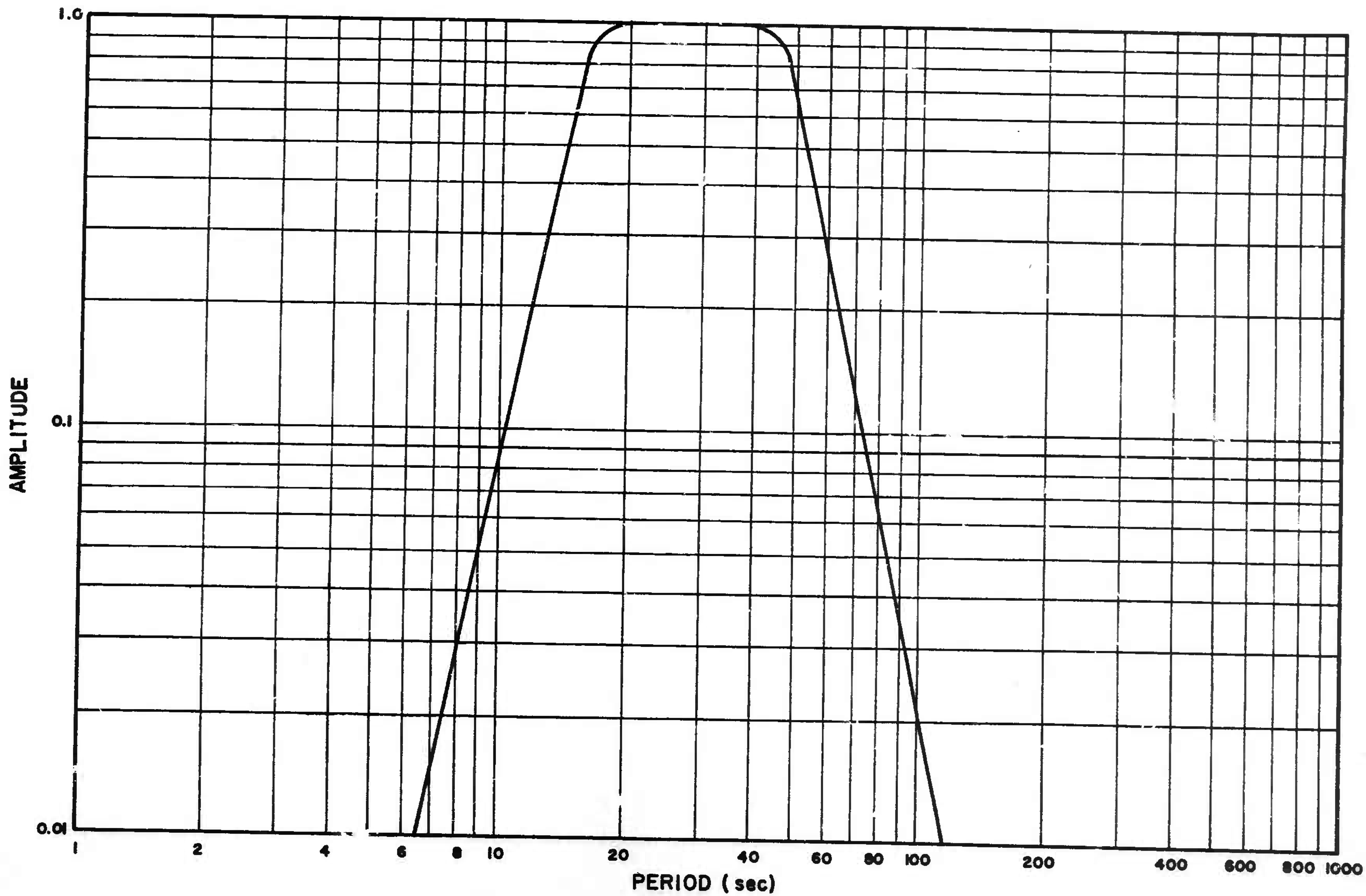

Figure 2 - Recursive Bandpass Filter Used in LPZ Data Preparation

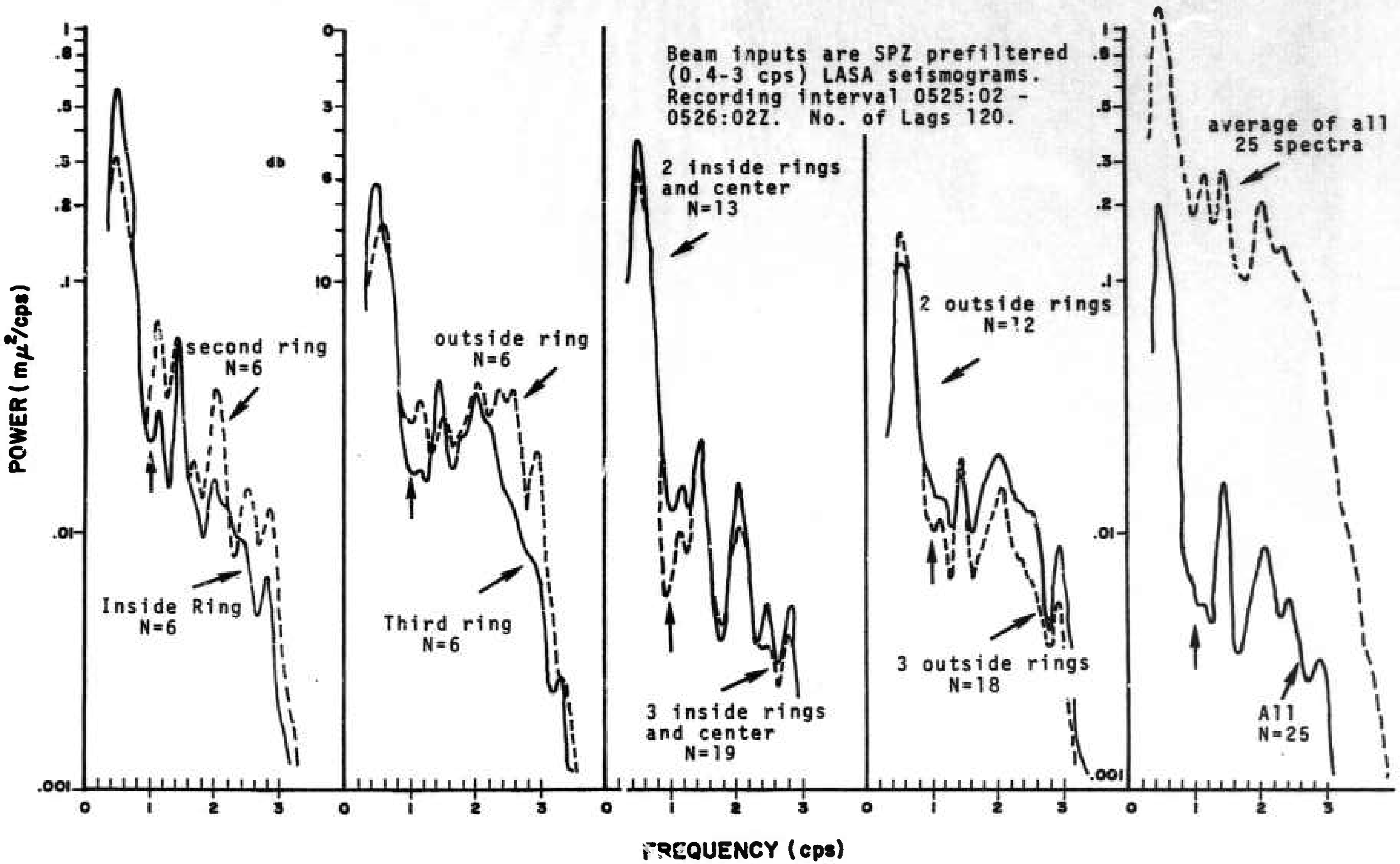

Figure 3 - Noise Power Spectra for E3 Beams - 08 March 1967

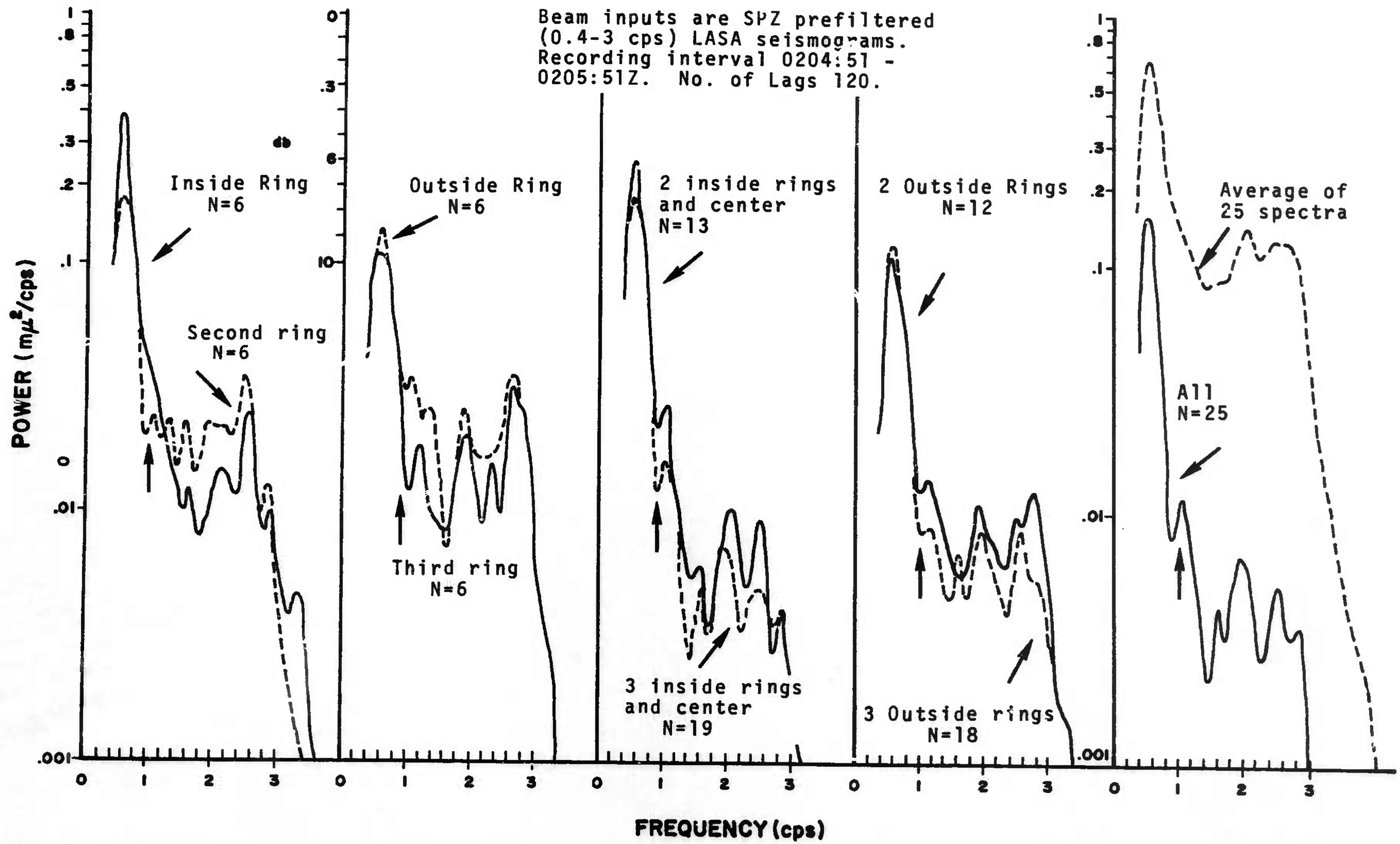

Figure 4 - Noise Power Spectra for E3 Beams - 10 March 1967

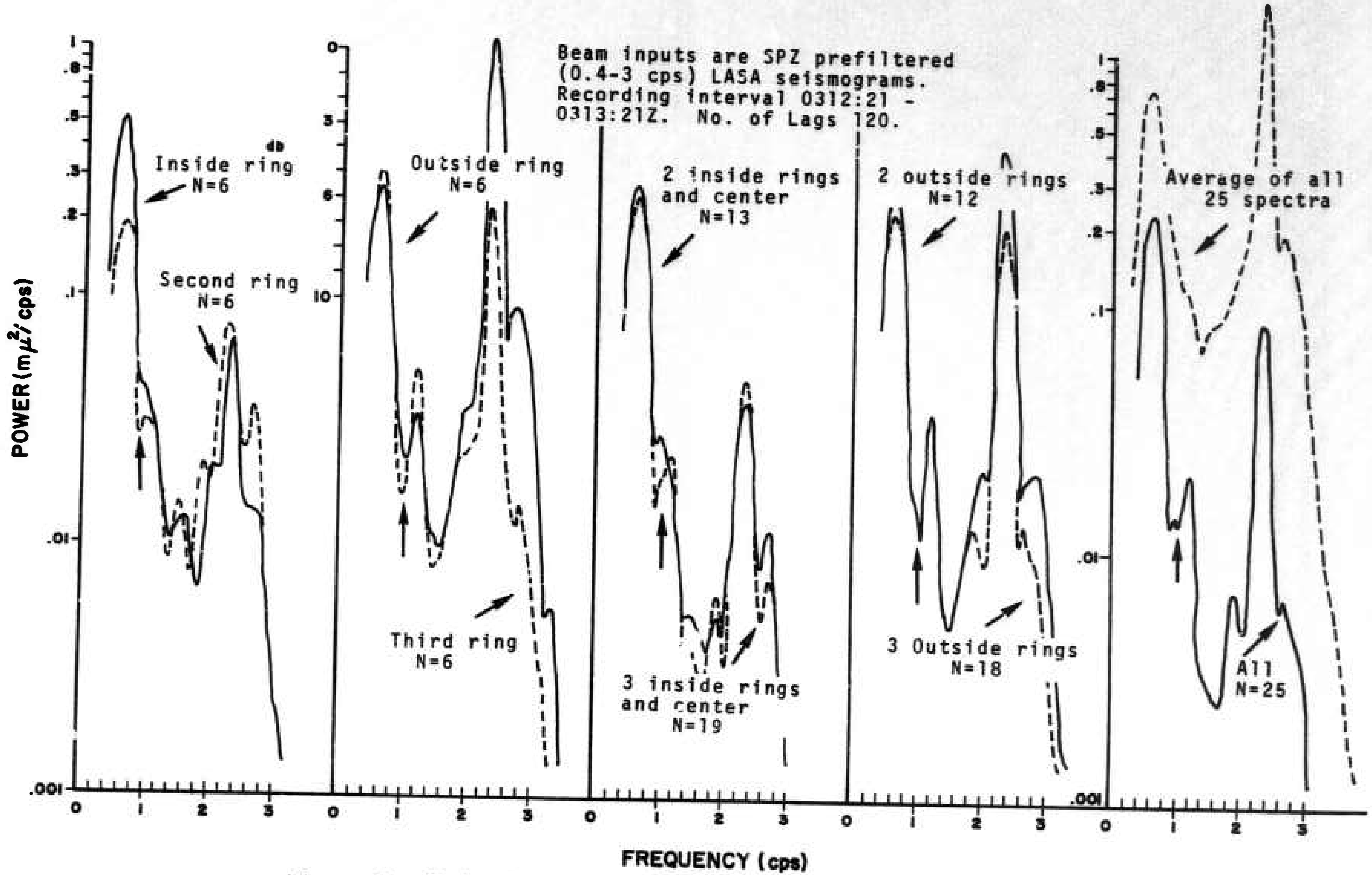

Figure 5 - Noise Power Spectra for E3 Beams - 11 March 1967

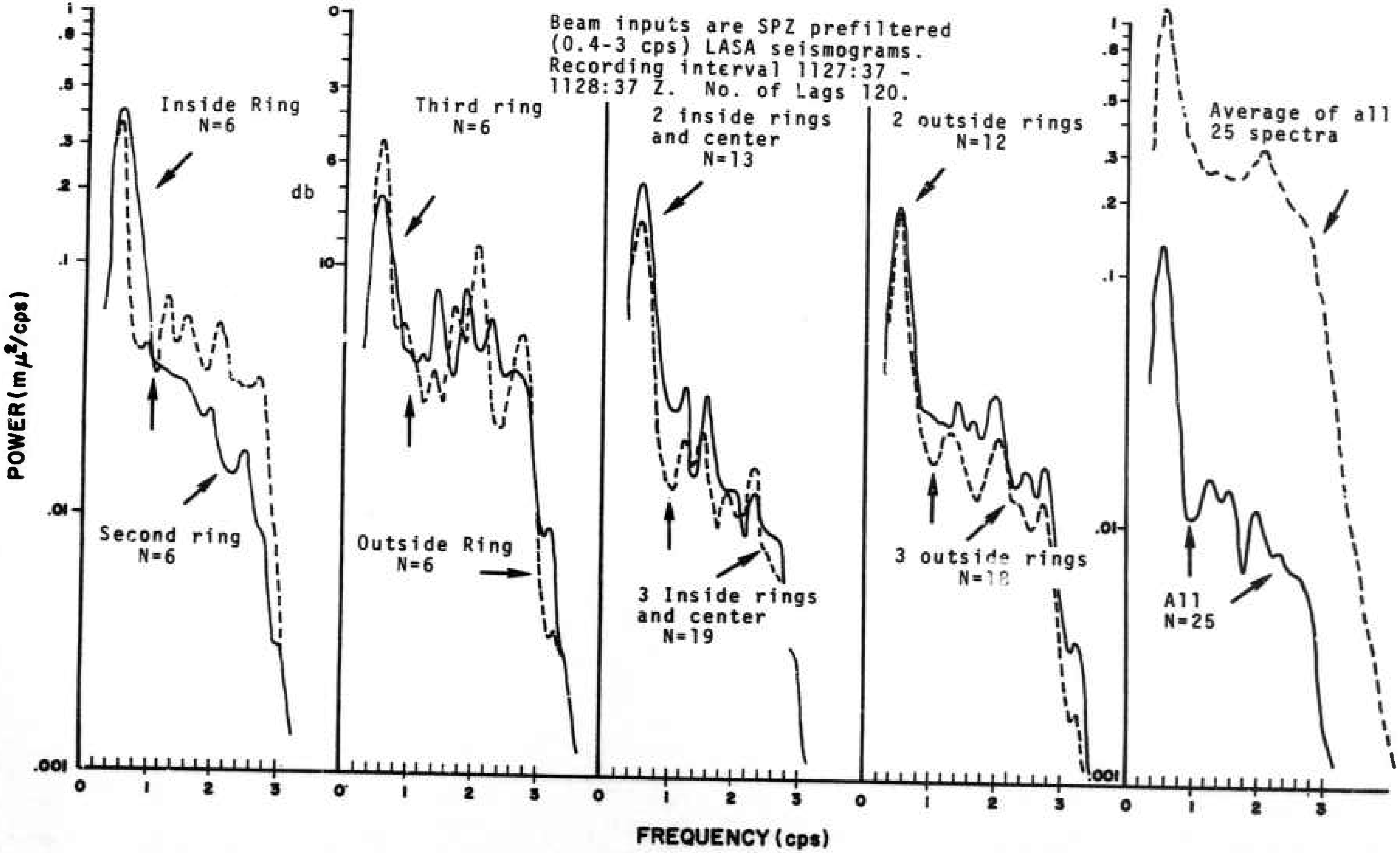

Figure 6 - Noise Power Spectra for E3 Beams - 17 March 1967

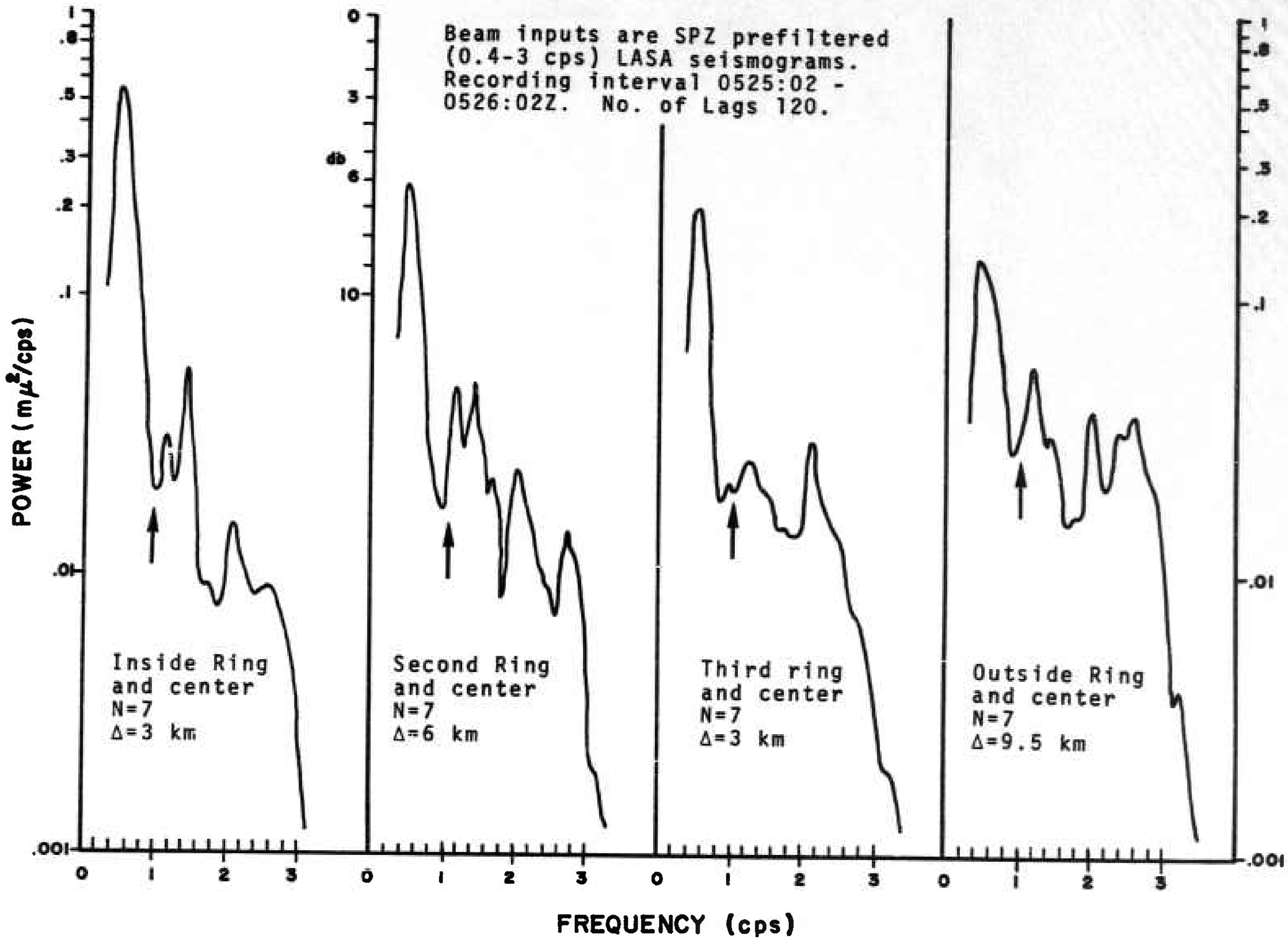

Figure 7 - Noise Power Spectra for 7-Element E3 Beams - 08 March 1967

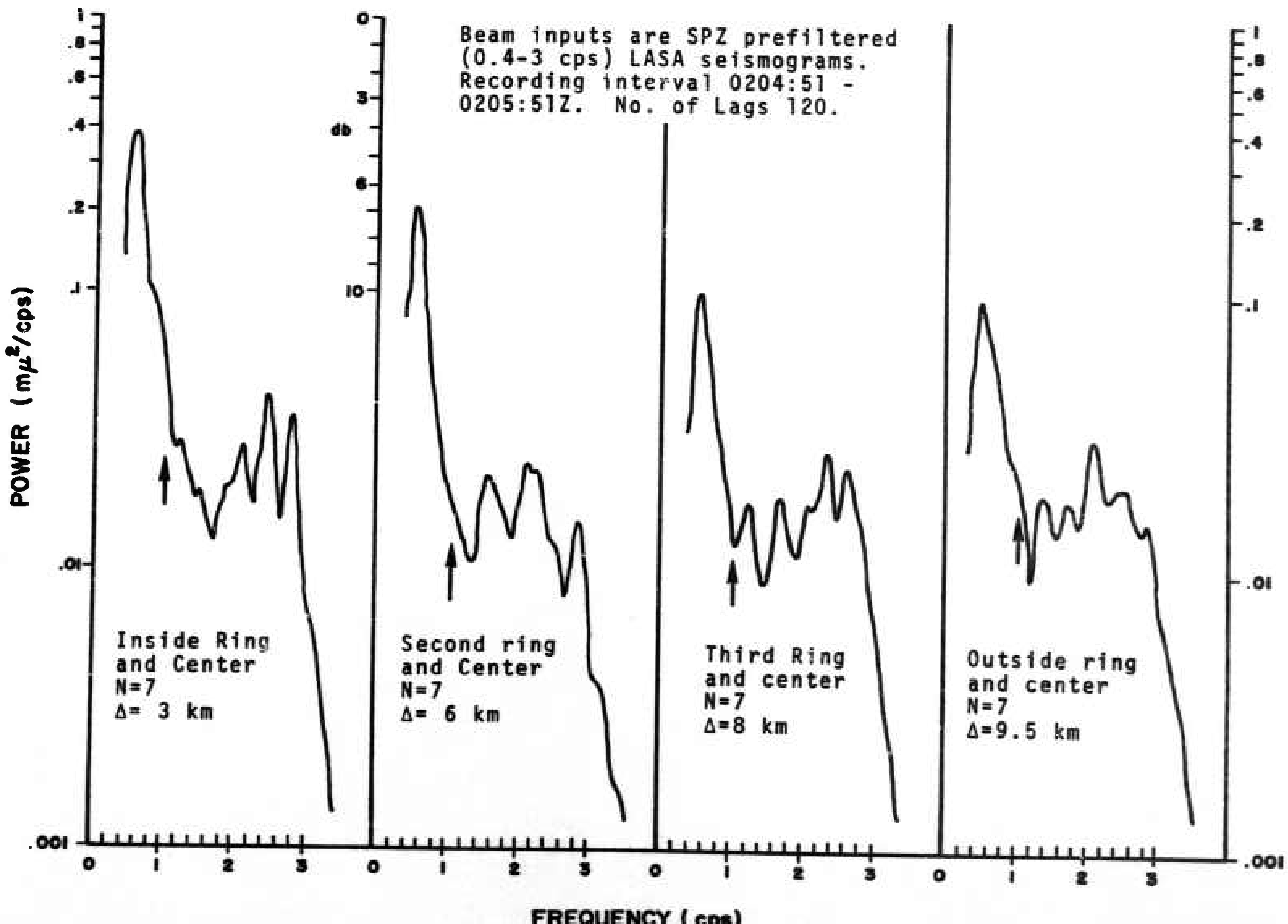

Figure 8 - Noise Power Spectra for 7-Element E3 Beams - 10 March 1967

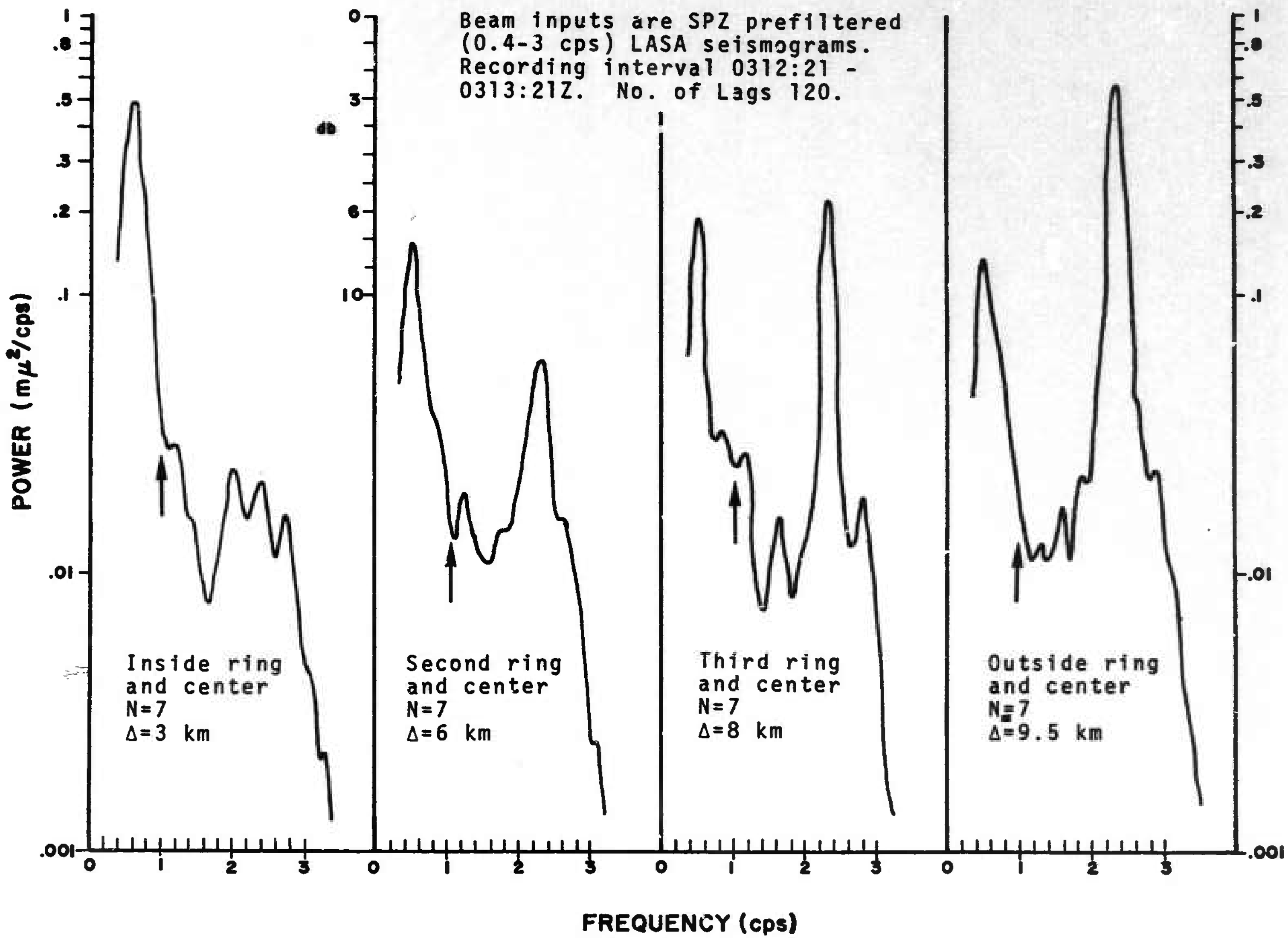

Figure 9 - Noise Power Spectra for 7-Element E3 Beams - 11 March 1967

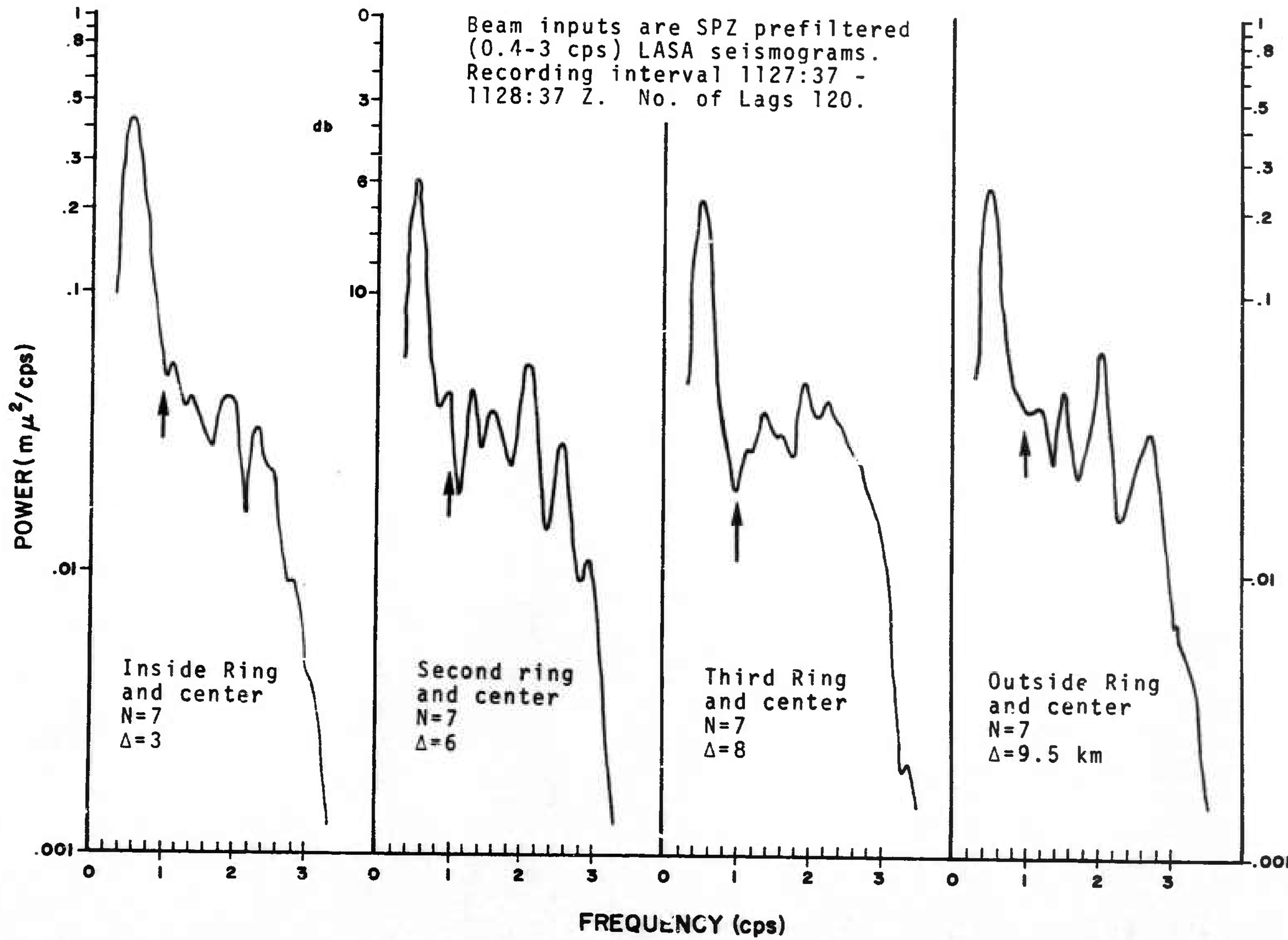

Figure 10 - Noise Power Spectra for 7-Element E3 Beams - 17 March 1967

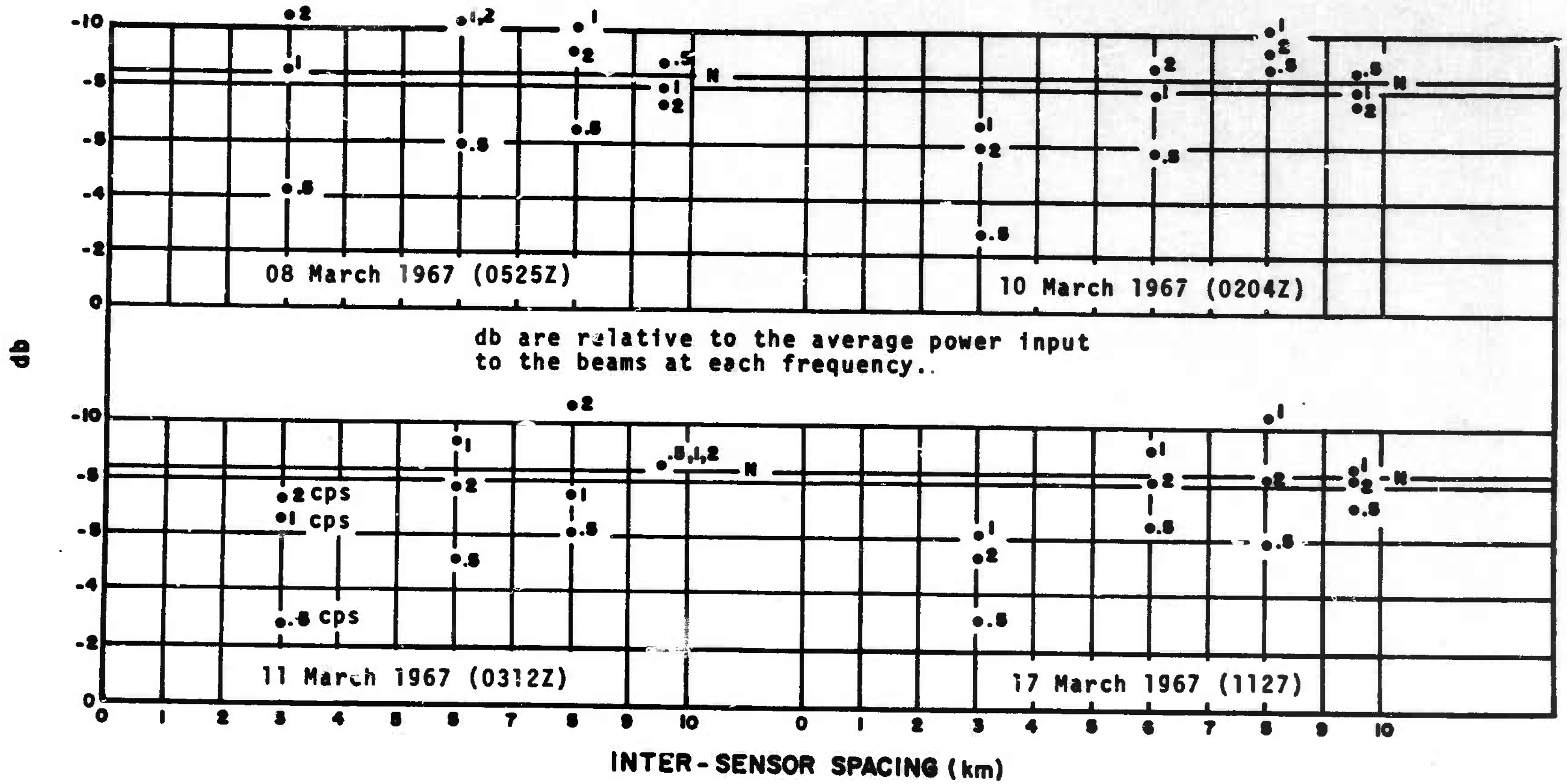

Figure 11 - Noise Power Reduction for 7-Element E3 Beams

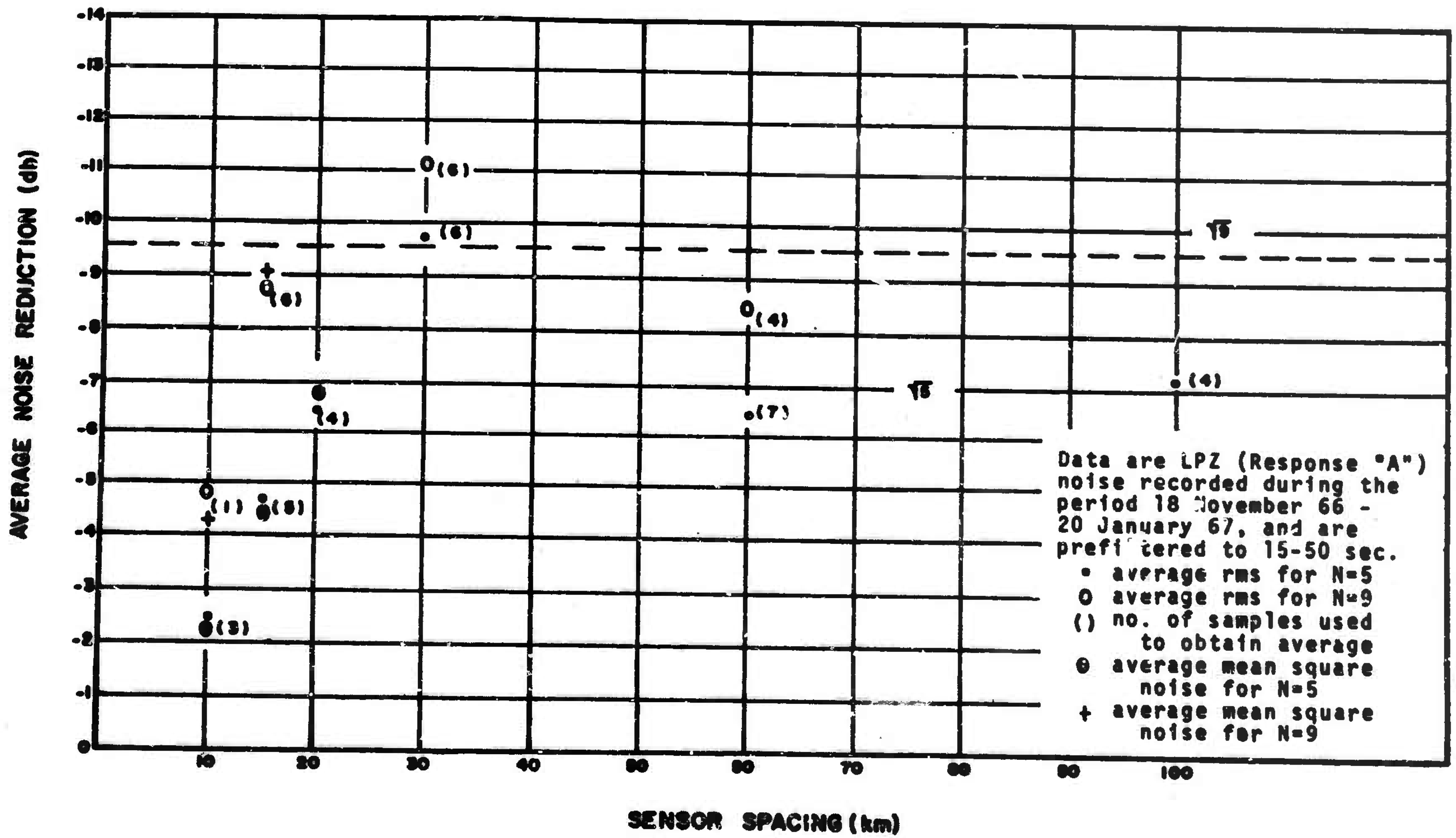

Figure 12 - Average Long Period Noise Reduction At The Montana LASA Using Two Experimental Methods.

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In those cases where the number of short-period beam inputs is held constant at 7 and spacing between adjacent sensors is changed progressively from 3 to 9.5 kilometers, noise power at 1 cps is reduced approximately by a factor of N for spacings equal to or greater than 6 kilometers.

If the number of long-period inputs to a beam is held constant at either 5 or 9 and spacing between adjacent sensors is changed progressively from 10 to 30 kilometers, the average rms level at the input and the noise based on zero-lag correlations are reduced approximately by a factor of $N^{1/2}$ for spacings greater than 20-30 km.

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Sensor-spacing						
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short-period						
noise reduction						

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